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Experimental Assessment of Performance And Emissions For Diesel Engine Powered With Biodiesel And HHO.

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Abstract: *The use of vegetable oils, which are not intended for human or animal consumption, as a fuel for diesel engines, appears to be an interesting solution to deal with the scarcity of fossil fuels and global warming caused by emissions of gases Greenhouse. The physicochemical characterization of two different types of plant seeds were used namely canola and jatropha plants. Also the use of Brown's gas (HHO gas i.e mixture of hydrogen and oxygen), reducing the amount of fuel and ensuring complete combustion of the mixture.The experimental tests were conducted on a diesel power engine; single cylinder, vertical, four stroke and air cooled direct injection to study the performance, emissions and combustion of biodiesel blends and HHO gas with diesel fuel. The results showed that using biodiesel blends and HHO gas decrease the brake specific fuel consumption values compared with pure diesel. It is clear that the minimum and maximum percentage saved values are 10.2% and 15.4% respectively compared with the pure diesel. The output torque was decreased when using Jatropha blends and increased when using Canola blends and the HHO gas compared with pure diesel. In case of exhaust emissions, using the HHO gas reduces the CO, NO and HC emissions.*

Keywords: *Biodiesel; diesel engine; performance; emissions; combustion.*

I. INTRODUCTION

The needs of energy are increasing rapidly in both developed and developing countries. There is 80% of the world's primary energy is of fossil origin. Unfortunately, the world's oil reserves are permanently declining and there is no real alternative today. Moreover, the use of this fossil energy contributes to the constant increase in emissions of greenhouse gases, in particular carbon dioxide whose consequences are now well established (climate change). For example, global anti-pollution legislation is increasingly stringent and generally falls within the global target of reducing greenhouse gases (e.g. CO_2) or other conventional pollutants (NOx, CO, and HC) [1]. Liquefied petroleum gas (LPG), natural gas, electric vehicles are considered for their "ecological character". Most of these markets, however, are currently undergoing little global expansion [2]; they remain transitional solutions. A handicap to their growth is their fossil roots and certain technical locks.

Today, efforts are focused largely on the quest for energy efficiency, the valorization of existing renewable energy sources and the search for new renewable energy sources that are low polluting. Biofuels are given special consideration in this sense. Such recognition is part of their role in reducing emissions of greenhouse gases. Biofuels are additional to this environmental aspect. Unfortunately, on the world scale, the current (first generation) biofuel sectors which are experiencing real development appear very insufficient. However, ongoing work on so-called second generation production chains will allow biofuels to occupy a larger share of total energy consumption. At the local level, the current (first generation) biofuels can present themselves as a real factor of development. As such, the use of vegetable oils as a substitute fuel (partial or total) to diesel or domestic heating oil in diesel engines and burners may be of interest to countries with potential for development of this sector, in this case the developing countries. These applications can be of the "short circuits" type (agricultural power plant, electricity production) or oriented in transport [3]. Over the last three decades, many studies have been achieved on the use of different vegetable oils and derivatives from vegetable oils in diesel engines or burners. [4, 5]. Proposals for technological solutions have been formulated to overcome these problems: modification or adaptation of the motor or of the burner, transesterification, mixing, cracking, micro emulsions etc. However, the results on overall performance (torque, efficiency), pollutant emissions and the preponderant parameters in the formation of pollutants during the combustion of vegetable oils remain subject to many divergences. Indeed, the mechanisms that govern the formation of pollutant emissions or which define performance, depend in large part on the type and operating conditions of the engine or burner and the physicochemical properties of the fuel. This dependence is very marked with vegetable oils; each vegetable oil must be considered with its specificities VAITILINGOM (1992). All vegetable oils have a similar overall behavior but each has its peculiarities related to its physicochemical nature. Generally, diesel engines and burners are optimized for use with hydrocarbons such as diesel. The substitution of this fossil fuel by a fuel of plant origin requires the determination of new optimal conditions of operation [6]. Given the growing interest in using vegetable oils in developing countries and the divergences in their environmental stakes or the reluctance to adapt them to current engines or burners, vegetable oils available in Egypt in engines or on burners.

It has been found that the biofuels as a kind of renewable clean energy resource and capable of replacing fossil fuel. Many biofuels have been proposed in the past by various workers, and their effects on engine performance and emissions have been studied. In this study, the topic is pursued in greater depth and the focus will shift towards biodiesel as an alternative fuel for diesel engines. Energy consumption is mainly based on the fossil fuels, which account for 87% among the different sources of energy. Crude oil represents of 32.87%, coal 30.06% and natural gas 23.73%, respectively. Renewable energy, nuclear energy and hydropower are very small in usage with only 2.19 %, 4.42% and 6.72% of the total energy usages, respectively. Transport accounts for thirty five percent of the total energy consumption of which 80 % is road transport [7]. Ethanol and biodiesel, often extracted from valuable agricultural crops, are the most widely recognized sources of biofuels for the transport sector. The European Union has introduced the use of biofuels or any renewable fuel to substitute diesel or gasoline for transport purposes in order to meet commitments on climate change and environmentally friendly health. In 1900, Rudolf Diesel succeeded in running a combustion engine using peanut oil as fuel and demonstrated it at the world exhibition in Paris. The use of vegetable oils for engine fuels becomes in course of time as important as petroleum and coal. With the appearance of low viscosity petroleum-based diesel, interest in the oils waned. Better engine performance, easy availability and favorable economics led to a steady growth in the use of petroleum-based fuels for most of the 20th century. The alcohols and vegetable oils (ethanol and methanol) are considered favorable renewable liquid fuels. For diesel engines, because of their low Cetane level, alcohols are not suitable for combustion [8]. Vegetable oils are not appropriate for spark ignition engines because of low volatility and low octane levels. The use of bio-diesel is therefore considered to be one of the best possible solutions to this problem. Bio-diesel and straight vegetable oil can be used as clean diesel fuel. There are many advantages are noted and reported with using bio-diesel and discussed with Banapurmath et al. [9], Rushang et al. [10], Sharma and Singh [11], and Hamed et al. [12]. There are different and several types of vegetable oils that can be used for biodiesel preparation. The most researchers studied soybean, sunflower, rapeseed and palm oils. The biodiesel characteristics are close to the mineral diesel and it can be used to replace the mineral diesel. There are about 10–11% oxygen by weight in vegetable oil esters that can be used to encourage combustion in engines [13]. Biodiesel is considered to be one of the first biofuel to be developed and used in the world, particularly in the European Union (EU). Today, the EU is the world's largest producer of biodiesel. Biodiesel represents about 80% of the total market for biofuels for transport in the EU [14]. Research has shown that biodiesel always produces less hydrocarbons, particulate matter, carbon monoxide, and sulfur dioxide emissions than pure diesel.

Saravanan et al. [15] studied the emission and the performance characteristics of a four stroke single acting cylinder compression ignition engine with Mahua oil which transesterified using methanol in the presence of alkali catalyst. They reported that the emissions of carbon monoxide, hydrocarbon for Mahua ester were decreased compared to diesel by 26% and 20% respectively. The power loss at full load was around 13% combined with 20% increase in fuel consumption. Rakopoulos et al. [16] researched the production of biodiesel from four vegetable oils. Sunflower, olives, cotton seeds and corn oils were used to test the efficiency of the minibus engine. They found a slight increase in NOx, very slight increase in released CO and a decrease in smoke when using vegetable oil.

Roy et al. [17] reviewed the processing of biodiesel from canola oil and compared the emissions from direct injection diesel engines. Studies have shown that canola biodiesel has very different fuel properties, emissions and engine performance. Pure canola oil up to 5% of diesel fuel produced less CO emissions than diesel fuel. NOx emissions can either be decreased or retained at a level similar to that of NOx. Eryilmaz et al. [18] investigated the manufacture of biodiesel from oil seeds in Turkey. Various oil seeds such as soybean, sunflower, peanuts, sesame, canola, safflower, cotton seed, hemp seed, flax seed and poppy seed were used. The findings have shown that such oils can be easily used in the production of biodiesel. Bang-Quan He [19] studied the emission characteristics of diesel engines using different biodiesel fuels. The study focused on the characteristics of particulate matter (PM), polyaromatic hydrocarbon (PAH) and nitrogen oxides (NOx). Results have shown that the addition of ethanol to biodiesel or biodiesel-diesel can reduce the NOx and PM emissions of diesel engines. The engine performance and emission characteristics were compared with dual biodiesel blends of palm and jatropha by Nalgundwar et al. [20]. In a single cylinder DI diesel engine with varying loads, they used a dual biodiesel blend, mixtures of two different biodiesel types namely palm and jatropha. Results showed that the average braking power for 90 percent diesel and 10 percent biodiesel mixture increased by 4.65 percent. Using 20% diesel and 80% biodiesel, the brake thermal efficiency increased by 15%. CO emissions decrease by 7.1 %, 17.7 %, and 14.5 %, compared to diesel, with samples containing 10 %, 20%, and 30 % respectively. The production of biodiesel from Salvia Macrosiphon Oil using ultrasonic system was examined by Hoseini et al. [21]. From results they found that the concentration of CO and HC emissions and the specific fuel consumption decreased even though the torque, brake power and concentrations of the NO_x emissions and CO_2 increased when using biodiesel-diesel blends. Can et al. [22] studied the effects of the canola biodiesel blends in 5%, 10%, 15% and 20% proportions with diesel fuel were investigated at four loads in a single-cylinder DI engine. The results showed that the BSFC increased up to 6.56% and BTE reduced up to 4.2% at the high load when canola biodiesel ratio increased to 20%. The NO_x emissions increased to 8.9%.

Brown's gas consists from hydrogen and oxygen coming from the electrolysis procedure of water. The water hybrid vehicle uses the HHO (Oxy-Hydrogen) generator to supply hydrogen by electrolysis on request. The electrolysis procedure occurs in the HHO dry cell when the ebb and flow begin to move through the stainless-steel plates. The water molecules are isolated as HHO gas is generated between the two terminals of the plates. Many different studies were performed on diesel and spark ignition engines to enhance the engine performance, reduce the brake specific fuel consumption and reduce the engine emissions. Ji and Wang [23] has experimentally studied the effect of using hydrogen addition with two volume fractions on engine performance. The results indicated that hydrogen raises the thermal performance of the brakes by 26.37 per cent to 31.56 per cent with 6 percent hydrogen blending level. The emissions of HC and CO2 are also reduced, but the emissions of NOx are increased by increasing the hydrogen addition. Sopena et al. [24] considered the emissions characteristics of the hydrogen and gasoline engines. The results revealed that the thermal efficiency of the hydrogen engine was greater than that of the gasoline engine, but the torque output of the hydrogen engine was poorer than that of the gasoline engine. Wang et al. [25] analysed the impact of hydrogen and hydroxy on gasoline engine efficiency at 1400 r.p.m. The results mirrored that the fuel flow rate decreased with the addition of hydrogen, but increased with the blending of hydroxy. Emissions of HC decreased, while NOx increased with increased hydrogen and hydroxy. CO emissions increased after hydrogen, but decreased with the use of hydroxy. Ismail et al. [26] researched the efficiency of a hybrid compression ignition engine using HHO from dry cell. The results exposed a 15 per cent reduction in fuel consumption, a 17 per cent reduction in CO, a 27 percent reduction in HC, a 1% increase in CO_2 and 15 per cent increase in O_2.

From the previous reviews, importance of increasing the engine performance while reducing the engine exhaust emission values is shown. The main objective of this study is to accomplish an experimental investigation on the performance and emissions of ICE fuelled by the biodiesel blends and HHO gas. The engine performance parameters like torque and brake specific fuel consumption are investigated in this research. In addition to the engine exhaust emission characteristics such as exhaust temperature, carbon monoxide, carbon dioxide, nitric oxide and hydrocarbon.

II. MATERIALS AND METHODS

2.1 Availability of canola and jatropha in Egypt

Canola is one of the most important oil crops and an important source of vegetable oil extraction after palm oil and soybean oil. The canola is grown in Egypt as a winter crop and the free-fatty acids types are cultivated. The canola is irrigated at intervals of 15-21 days depending on the nature of the soil, the prevailing weather conditions and the growth of the plant. Harvesting is done early in the morning by cutting the plants and placing them in piles in the form of a pyramid to complete the drought for 7-10 days, taking into account not to delay the harvesting so as not to waste seeds. Average yield per acre is between 900-1500 kg of seeds according to the application of technical recommendations. In Egypt canola is grown in winter and irrigated once a month and doesn't need much water. The oil ratio in the seed is about 40~49% approximately. In subtropical and tropical climates, Jatropha grows well and can withstand temperatures, but does not tolerate frost. The seeds are cultivated by improved seeds, which are submerged in cow manure for 12 hours. Irrigation is necessary immediately after planting if the jatropha seedlings are prepared in the nursery. It should be on the third day after transplantation twice a week during the fall and 3 times a week during the summer. It is then reported every two weeks to ensure successful production. Jatropha's cultivation has been successful in Upper Egypt (Luxor City), where agriculture has been replaced by sewage irrigated forests as part of a national project for the safe use of treated sewage in tree-planting forests. Cultivations have excelled in Luxor city on her counterpart in many countries, an increase vegetative growth and fruit of 18 months after planting seedlings.

2.2 The HHO dry cell

the HHO dry cell design can vary in shape and size depending on the purpose of the cell and the amount of the gas needed from the cell. According to the electrolysis process, the plates should be made of metal that has the suitable properties, specifically good electrical conductivity, corrosion resistance, corrosion resistance lightness, good thermal properties and good physical properties. So the HHO dry cell was fabricated and mauufactured from stainless steel 316L and has ten plates. It consists of three active plates, O-ring, two pieces of acrylic plastic, steel nails, hoses, water tank and bubbler. The gasket and the O-rings are used to provide a tight seal over a range of pressures, temperatures, and tolerances. An acrylic plastic is used to cover the plates and the sealing agent. It contains the inlet and outlet holes of water and gases because it resists chemicals, shrinkage and is highly transparent. The HHO gas dryer -also HHO gas bubbler - is used for safety leveling the water in case of overflow. The bubbler has more than one job, it is very important to get maximum protection for hydrogen safety. Suitable water tank for all HHO systems is made from flame-retardant plastics. The tank allows the water to circulate in the generator and is used for a cooling running system and lower amp draw.

2.3 Processes of oils production

Initially the oilseeds from the products are weighed and sent to the first step to clean from impurities such as pods, sand, sticks and dust. Magnetic force and screening equipment are used to pulls the tramp metals and remove impurities from the seeds. A dryer is used to remove the moisture content from the seeds to prevent deterioration during storage. A differential speeds cracking mill is used to crack these seeds into small parts. A flaking mill is used to perform fibber flaking operation for seeds in different ranges from 0.3 to 0.4 mm thick and from 8 to 18 mm diameter. Cooking is performed during 120 minutes with temperatures around 87.8°C to break down cell walls and reduce oil viscosity, allow the oil to escape and control the moisture content. The key physicochemical properties of the diesel and neat biodiesel are listed in Tables 1

Table (1): *The properties of the blend fuel compared with pure diesel*

Properties	Unit	Pure Diesel fuel	Jatropha 50% + Diesel 50%	Canola 50% + Diesel 50%
Kinematic viscosity @ 40 °C	$mm^2\ s^{-1}$	2.719	3.9	3.78
Density @ 15 °C	$kg\ m^{-3}$	851.9	871.3	891.5
Acid number	$mg\ KOH\ g^{-1}$	0.12	0.27	0.35
Calorific value	$MJ\ kg^{-1}$	45.31	42.57	41.48
Flash point	°C	71.5	103.5	110
Pour point	°C	1	0	> -2
Cloud point	°C	8	6	-1
Oxidation stability @ 100 °C	Hours	>40	10.8	17
Cetane number	----	52	56	46

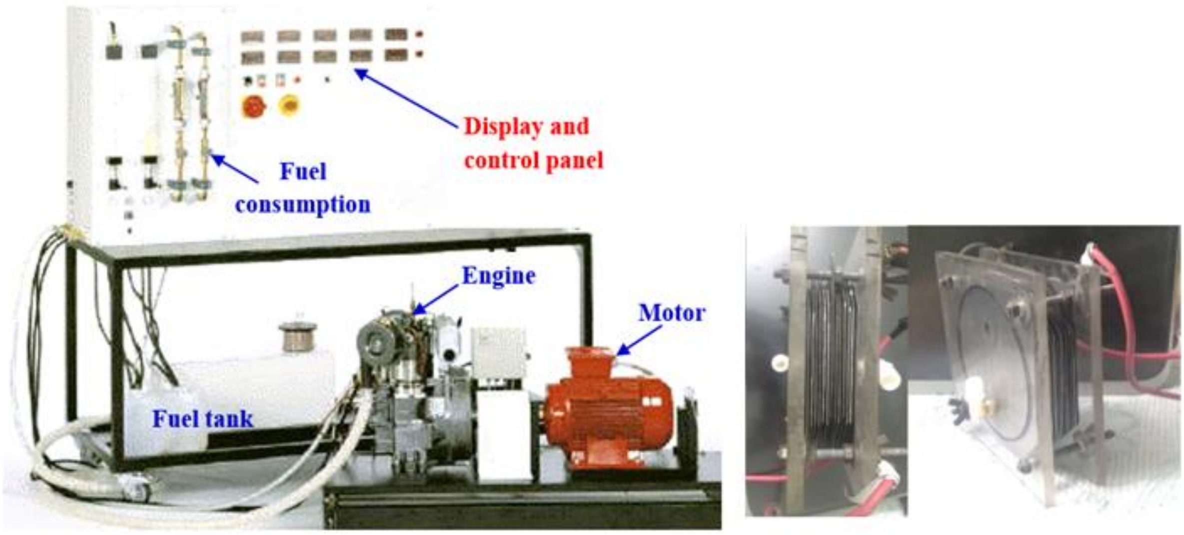
III. EXPERIMENTAL SETUP AND PROCEDURES

Experiments were carried out on a diesel power engine (an engine is coupled with an electrical generator). The engine is a single cylinder, vertical, four strokes, naturally aspirated and air-cooled direct injection diesel engine. The technical specifications of the diesel engine are given in the Table 2. The electric generator was loaded with four lamb each one has 500 watts connected in parallel was used to supply the load applied to the generator. After the formulation of biodiesel and HHO gas, engine tests were conducted at a different speed (900 - 2000 rpm). All various thermodynamic parameters, such as temperatures, pressures, and air and fuel flow rates, are constantly calculated in order to achieve engine performance. Mechanical parameters such as engine torque and rotational speed are also calculated with other parameters. Figs. 1 and 2 present a photograph and schematic diagram of the experimental setup with the HHO dry cell. Pilot diesel fuel is injected to cover 10% approximately of the maximum power output when using dual fuel operating mode at the rated engine speed. Then, keeping constant the flow rate of liquid diesel fuel, the engine power output is increased by augmenting the natural gas flow rate. This procedure is followed until the desired power output is obtained [27].

A gas analyser is used to measures the chemical content of the exhaust gases (emissions resulting from the combustion engine); identify engine performance and test the running efficiency of the engine. The computerized gas and smoke analyser is used to measure the exhaust gases of hydrocarbon HC, nitrogen oxides NO_x and carbon monoxide CO in addition to carbon dioxide CO_2 and oxygen O_2, as shown in Table 3. The experiment is equipped with the programmable application "ANOI Software" and the results will appear on the computer. To order to know the consistency and strength of the experimental results, an uncertainty test is needed to prove random errors in the experimental setup. Kanoglu [28] presents a detailed method for calculating and evaluating the error analysis of the measured and calculated parameters. The average values for uncertainties of some measured and calculated parameters is shown in Table 4.

Table (2): Engine specification

Bore, mm	Stroke, mm	Displacement, L	Normal speed, r.p.m	Normal power, kW	Mean effective pressure, kPa
78	62	0.296	1000- 2000	5 – 5.5	540.5 – 496.6



(a)The diesel engine *(b) HHO dry cell*

Fig. 1 *Photograph of the experimental setup.*

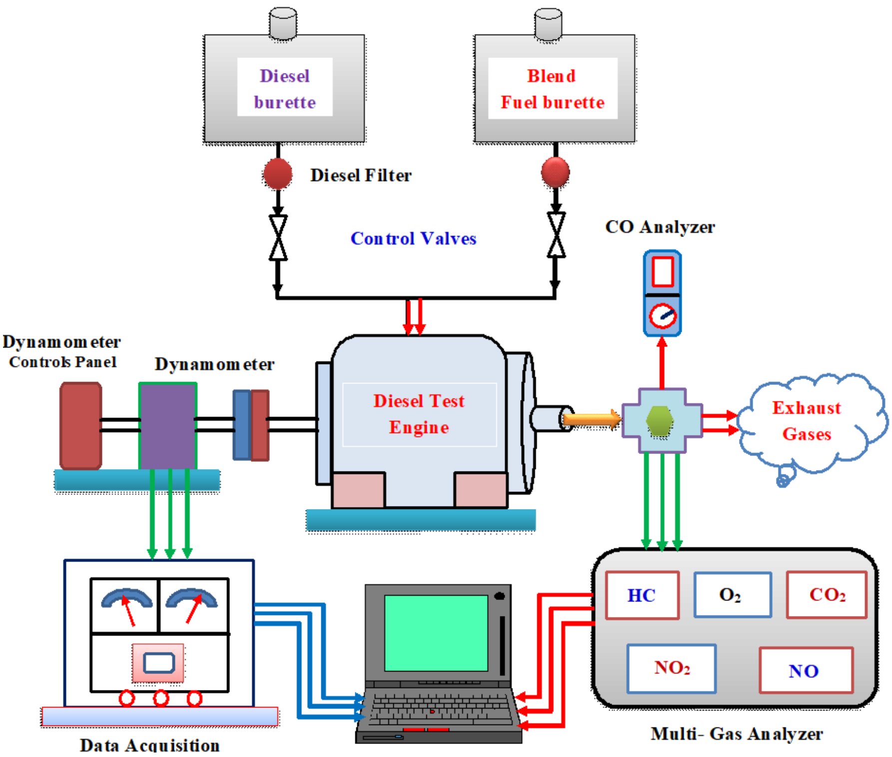


Fig. 2 *Schematic diagram of the experimental setup.*

Table (3): *Specifications of the exhaust gas analyzer*

Species	Detection	Range	Resolution	Uncertainty
CO_2	Infrared	0 - 20%	0.1%	± 5%
HC	FID	0 - 20000 ppm	± 10 ppm	± 5%
CO	Infrared	0 - 5000 ppm	1 ppm	± 5%
O_2	Galvanic cell	0 - 25%	0.1%	± 5%
NO_x	chemiluminescence	0 - 5000 ppm	1 ppm	± 5%

Table (4): *The average values for uncertainties and errors of some measured and calculated parameters.*

Parameters	Range	Accuracy	Error (%)
Temperature (^oC)	0 – 800	± 1.0	0.12
Speed (rpm)	0 - 5000	± 10	0.2
Fuel consumption (L/min)	0 – 50	± 1.0	2.0
Torque meter (N.m)	0 – 50	± 0.1	0.2

IV. RESULTS AND DISCUSSION

In this study, biodiesels fuel of Jatropha and Canola were obtained from Egypt. The biodiesels production were conducted via the acid-esterification and alkali-transesterification process. From the analysis of the formed biodiesel, it can be observed that the physicochemical properties was comprehensively measured and compared with the biodiesel standards based on the EN14214 and ASTM D6751. Also, from the analysis, it appears that the physicochemical properties of jatropha biodiesel are enough to meet the EN and ASTM biodiesel standards. Thus, the produced biodiesel can be used in normal diesel engines without any modifications [29]. Also the generated hydroxy gas from the HHO dry cell entered the engine from the intake suction pipe and the gas rate was set to ensure constant rotation for the engine.

4.1 Engine Performance

4.1.1 Torque

The results of the engine's speed and torque, at full load, are shown in Fig. 3. It can be observed that the biodiesel blend of Jatropha 50%+ Diesel 50% fuel resulted in lower torque relative to the diesel fuel. This occurs due to the lower heat of combustion of the fuel blend and lower fuel delivery at full load due to the higher mass flow rate required from the fixed nozzle area. The output torque was decreased when using Jatropha 50%+ Diesel 50% and increased when using Canola 50%+ Diesel 50% compared with pure diesel. On the other hand, the HHO gas increased the engine output torque compared with pure diesel as shown in the figure. At engine speed of 2000 rpm the measured recorded torque was 21.35, 19.5, 22.32 and 23.2 N.m for Diesel, Jatropha 50%+ Diesel 50%, Canola 50%+ Diesel 50% and Diesel+ HHO gas 10% respectively. The published research of biodiesel blend showed similar torque recoveries as reported by the Ref. [30, 31].

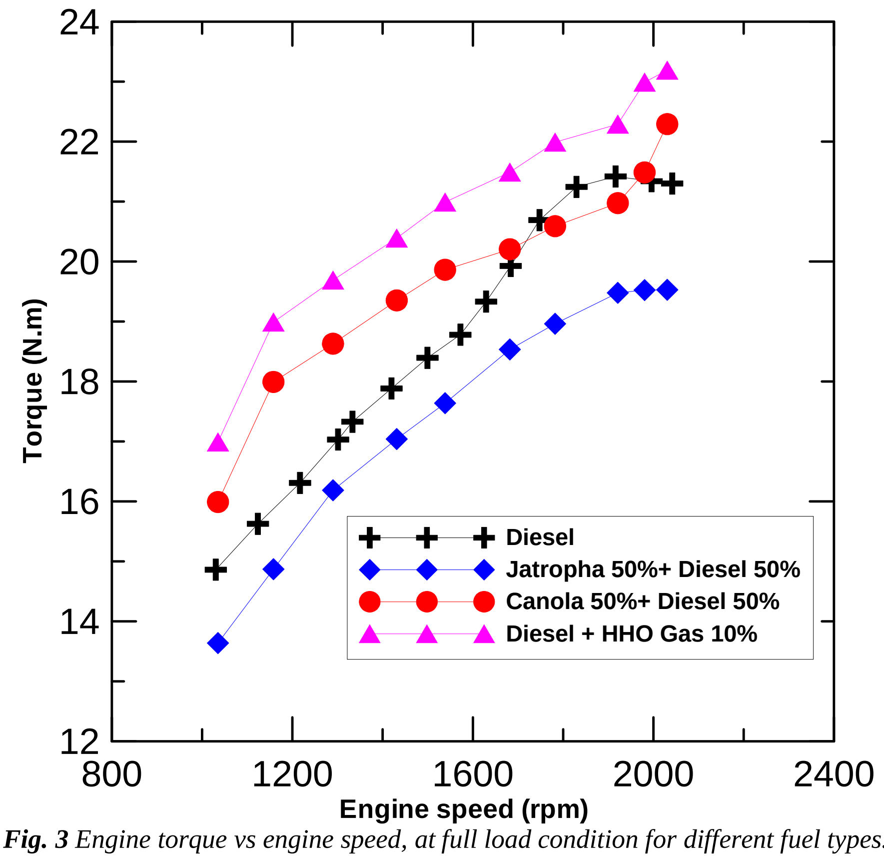


Fig. 3 *Engine torque vs engine speed, at full load condition for different fuel types.*

4.1.2 Brake Specific fuel consumption

The results of the engine tests provided the values needed to calculate the brake specific fuel consumption for each type of fuel. Measurement of the fuel flow at the engine shaft allowed the deduction of the brake specific fuel consumption (BSFC) at the different operating points as shown in Fig. 4. From the analysis of this figure it can be noticed that at high load the BSFC increases with the increase in the amount of biodiesel. It is also to be seen through this figure, the evolution of the brake specific fuel consumption according to the engine speed of all the fuels tested. At low load, the values of the brake specific fuel consumption for Jatropha 50%+ Diesel 50%, Canola 50%+ Diesel 50% are slightly higher compared to the diesel specific consumption. The maximum recorded values of brake specific fuel consumption for Diesel, Jatropha 50%+ Diesel 50%, Canola 50%+ Diesel 50% and Diesel+ HHO gas 10% are 0.398, 0.469, 0.552 and 0.364 kg/kW.hr respectively. Based on the results obtained, it can be said that Jatropha or Canola biodiesel are suitable for replacing diesel fuel in the diesel engine. This observation is consistent with the Refs. [32]. Also, the HHO gas can be used to save a high percentage in break specific fuel consumption. The minimum and maximum percentage saved values of HHO gas are 10.2 and 15.4% respectively compared with the pure diesel.

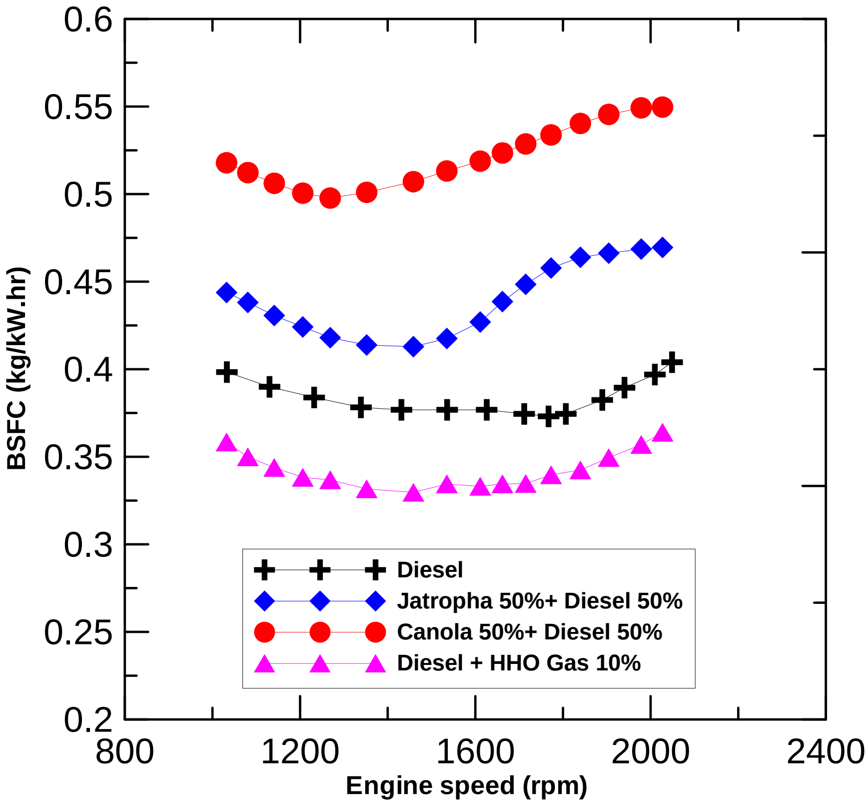


Fig. 4 *Brake specific fuel consumption vs engine speed, at full load condition for different fuel types.*

4.2 Exhaust Emission Characteristics

4.2.1 Exhaust temperature

The variation of exhaust gas temperatures with engine speed for the different fuel blends examined is shown in Fig. 5. The analysis of the results reported that, for all operating points studied, the temperature of the gases is linearly proportional to the engine speed. The maximum recorded values of exhaust gas temperatures for Diesel, Jatropha 50%+ Diesel 50%, Canola 50%+ Diesel 50% and Diesel+ HHO gas 10% are 270.1, 231.2, 237.8 and 250.3 ^{o}C respectively. In general, the exhaust gas temperatures of biodiesel and its mixtures are lower than that obtained when the engine is fuelled with diesel fuel and at high engine speeds, the exhaust temperature of all fuel mixtures rise as shown in Fig. 5. Also, the exhaust gas temperature is directly related to the engine speed, and that using the HHO gas reduces the exhaust gas temperature. This is due to the power device that gives better ignition and cleaner gasses.

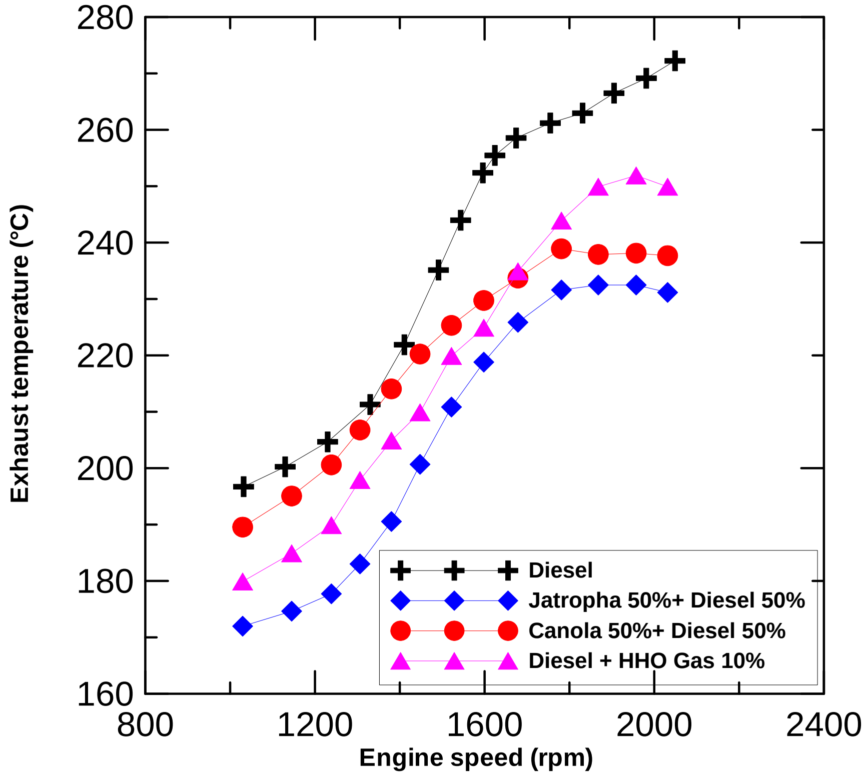


Fig.5 *Exhaust gas temperature vs engine speed at full load condition with different full types*

4.2.2 Carbon Monoxide

The emissions of carbon monoxide (CO) for the various fuels tested were measured as function of the engine speed and shown in Fig. 6. Due to the molecular oxygen absence in the fuel, the combustion was incomplete, and the emissions of carbon monoxide was emitted. In general, there are many factors that affect the CO emissions such as the engine speed, the air-fuel ratio, the pressure, the injection timing and the fuel type [33]. For most of the previous literature review, the reduction in CO emissions when replacing biodiesel to diesel fuel can be considered the general trend [34]. However, some authors did not find any difference between biodiesel and diesel, and even significant increases in the use of biodiesel [35]. As shown in Fig. 6, the formation of carbon dioxide decreases with increasing engine speeds for Diesel, Jatropha 50%+ Diesel 50%, Canola 50%+ Diesel 50% and Diesel+ HHO gas 10% up to 1700 rpm, then increases with increased speed. The maximum recorded values of carbon monoxide (CO) for Diesel, Jatropha 50%+ Diesel 50%, Canola 50%+ Diesel 50% and Diesel+ HHO gas 10% are 444.46, 216.3, 243.2 and 190 ppm respectively. Utilizing a mix of HHO gas decreases the presence of carbon monoxide in the fumes. CO production has to do with the effectiveness of the burning in the engine and furthermore is exceedingly influenced by the fuel to air proportion of the engine. It has been demonstrated that adding HHO gas to the combustion advances the combustion efficiency and specific fuel consumption

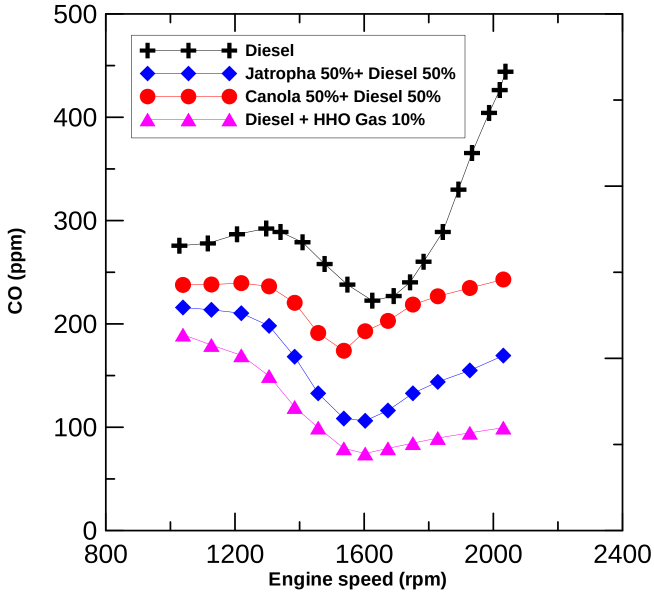


Fig. 6 *Carbon monoxide emission vs engine speed at full load condition with different full types*

4.2.3 Carbon dioxide

Fig. 7 shows the variation of CO_2 emissions as function of the engine speed, at full load condition for all fuel tests. From the analysis of this figure it can be noticed that the CO_2 emissions increases when the engine speed increase and the amount of CO_2 is proportional to the amount of fuel burned. The carbon dioxide production from the fossil fuels combustion causes an accumulation of carbon dioxide in the atmosphere and causes many environmental problems. Although biofuel combustion produces emissions of carbon dioxide, absorption by crops helps to maintain CO_2 levels in the environmental [36]. In the cylinders, the rich fuel mixture at a fixed throttle position brings more CO_2 production at low engine speeds. At engine speed of 2000 rpm, the maximum recorded values of CO_2 for Diesel, Jatropha 50%+ Diesel 50%, Canola 50%+ Diesel 50% and Diesel+ HHO gas 10% are 9.21, 9.45, 9.55 and 9.6% respectively. The results also showed that the high percentage of Canola 50%+ Diesel 50% biodiesel blend, produce high CO_2 level. The reason of increasing CO_2 in the exhaust may be due to the excess oxygen present in the biodiesel which reacts with CO to produce the CO_2. Also using HHO gas gives high percentage of CO_2 at high engine speed compared with the pure diesel and its blends as shown in the figure.

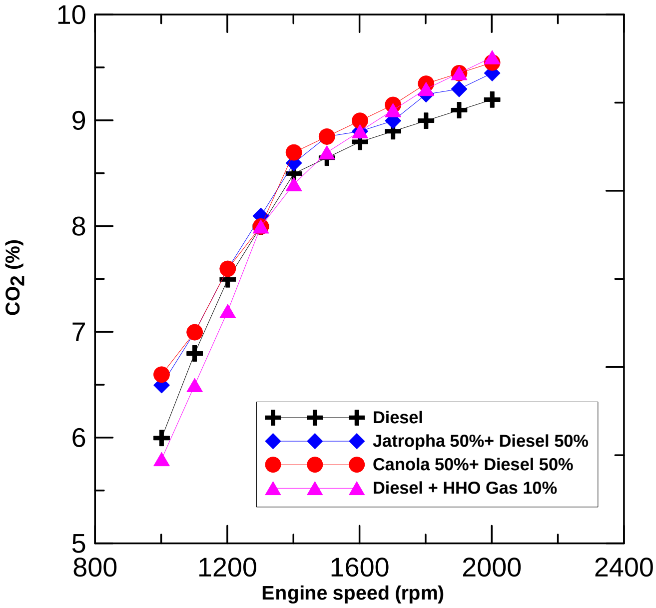


Fig. 7 Carbon dioxide emission vs engine speed at full load condition with different full types

4.2.4 Nitric oxide

It should be remembered that the emissions of nitrogen oxides (NO_x) from diesel engines is a major concern. The NO_x is mainly composed of nitric oxide (NO) and nitrogen dioxide (NO_2). The proportion of NO_2 is typically about 10-20% of the total nitrogen oxide emissions. The formation of thermal NO_x is predominant in the diesel engine. Most thermal NO_x is formed in diesel engines at the start of the combustion process, when the piston is near the top dead center. The temperature and pressure of the charge are then at their maximum value. Most of the NO_x is actually formed during the premixed combustion phase. Fig. 8 summarizes the measured results of nitrogen oxide emissions as a result of the combustion of the formulated fuels. Indeed, as in diesel engines, most NO_x are formed at the beginning of the combustion process, the temperature increases with the charge (Fig. 5), which gives favorable conditions for the formation of nitrogen oxides. The results showed that the NO higher values for blending biodiesel than diesel fuel. This finding is consistent with the studies published by other researchers [37]. On average, at engine speed of 2000 rpm, the maximum recorded values of NO_x for pure Diesel, Jatropha 50%+ Diesel 50%, Canola 50%+ Diesel 50% and Diesel+ HHO gas 10% are 72.41, 83.1, 98.13 and 55.12 ppm respectively. This result can be attributed to the low air / fuel ratio because biodiesel is an oxygen fuel and contains 12% more molecular oxygen than diesel, which increases the ambient temperature and improves combustion [38]. Introducing HHO into the engine intake results in reducing the amount of gasoline, which leads to lean mixture, resulting in reduction in the flame temperature. Therefore, lower NO emission is obtained as shown in Fig. 8. HHO gas shifts all emission curves downward, since it enhances the combustion characteristics and consequently reduces the fuel consumption at any speed.

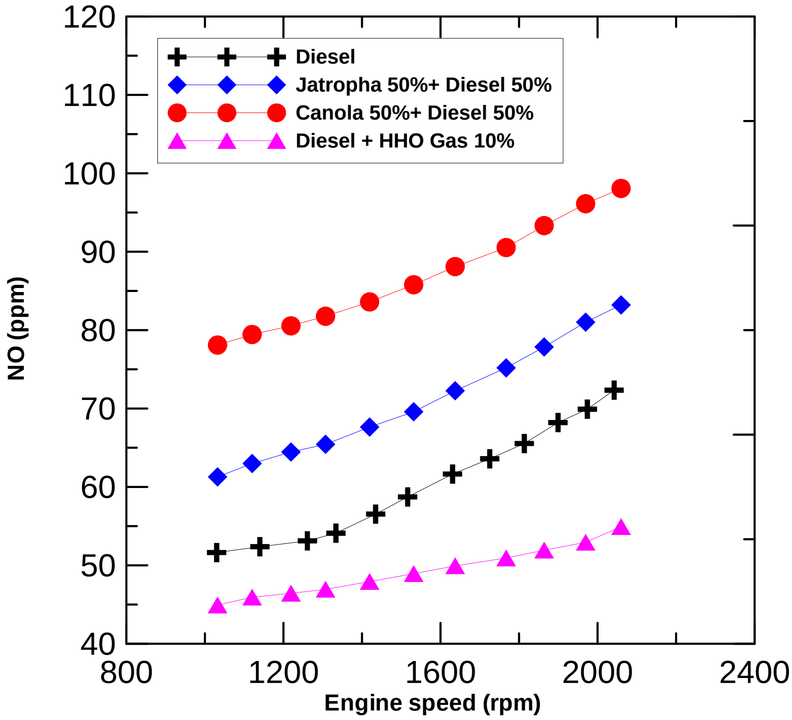


Fig. 8 *Nitric oxide emission vs engine speed, at full load condition with different full types.*

4.2.5 Hydrocarbon

The hydrocarbon (HC) emission may be in the form of unburned or partially burned fuel. The cause of the hydrocarbon emission is entirely related to the combustion process. Incomplete combustion produces a hydrocarbon emission. In the combustion process, if a fuel-rich mixture does not get enough oxygen to react with the entire carbon fraction, a higher hydrocarbon level is emitted. The results of the unburned hydrocarbon emission measurements carried out during the tests on the combustion of diesel fuel and net biodiesel are presented in Fig. 9. The variation of the emission of hydrocarbons as function of the engine speed, at full load condition is similar for all the fuels tested. The general trend is a gradual decrease in HC emissions as a function of the engine speed. Increasing the amount of fuel injected, due to excessive engine loadings, leads to the formation of the rich air/fuel mixture; which results in the production of unburnt. It appears that the HC emission rate is lower with the use of net biodiesel blends compared to diesel fuel. The higher the biodiesel fraction in the mixture, the lower the hydrocarbon emission. Since the increase in oxygen content, due to the increase of the biodiesel fraction, leads to a complete fuel combustion and the elimination of fuel-rich in the combustion chamber, the levels of emissions are reduced. At engine speed of 2000 rpm, the minimum recorded values of HC for pure Diesel, Jatropha 50%+ Diesel 50%, Canola 50%+ Diesel 50% and Diesel+ HHO gas 10% are 11.51, 10.01, 11.02 and 9.51 ppm respectively. Also, it can see that HC focus in the fumes is inversely proportional to the engine speed. This is because of an expansion in the turbulence force blending procedure of consumed and unburnt gasses which builds oxidation rate of HC. Additionally, a diminishment in HC concentration in the fumes because of presenting HHO is noted. This lessening in HC emission is expanded with engine speed.

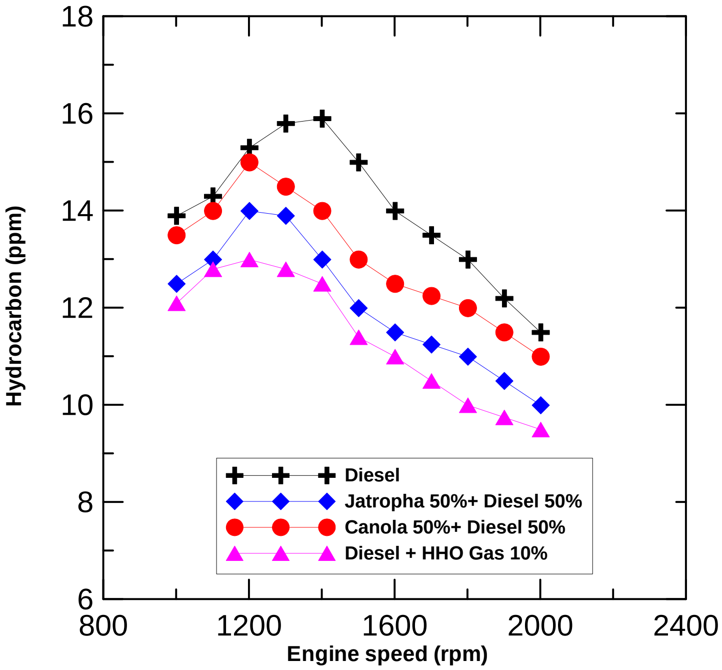


Fig. 9 *Hydrocarbons emission vs engine speed, at full load condition with different full types.*

V. CONCLUSIONS

Various fuels formulated based on eucalyptus biodiesel blends using the transesterification process were tested in a diesel engine. HHO dry cell was used to increase the engine performance and reduce the engine exhaust emission values. The results were analyzed and compared, both in terms of engine performance and pollutant emissions. The results showed that the maximum recorded values of brake specific fuel consumption for Diesel, Jatropha 50%+ Diesel 50%, Canola 50%+ Diesel 50% and Diesel+ HHO gas 10% are 0.398, 0.469, 0.552 and 0.364 kg/kW.hr respectively. In terms of the pollutant emissions, the maximum recorded values of carbon monoxide (CO) for Diesel, Jatropha 50%+ Diesel 50%, Canola 50%+ Diesel 50% and Diesel+ HHO gas 10% are 444.46, 216.3, 243.2 and 190 ppm respectively. Finally using HHO gas reduces the NO emissions and the HC emissions. At engine speed of 2000 rpm, the minimum recorded values of HC for pure Diesel, Jatropha 50%+ Diesel 50%, Canola 50%+ Diesel 50% and Diesel+ HHO gas 10% are 11.51, 10.01, 11.02 and 9.51 ppm respectively.

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